Final Report - 2015
ISDA Nursery, Landscape, and Florists Grant Program

Title: Establishment of Wildflower Plantings in Urban and Suburban Sites

NAC/ISDA 2015-1

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Abstract

Planting attractive, sustainable wildflower meadows in private and public green spaces is becoming increasingly popular. Weed competition is the single largest barrier to successful establishment of naturalized wildflower meadow plantings. An establishment method was designed and tested that is based on plant succession principles and involving a 3-step, grass-first protocol for reducing weed competition: 1) spring planting of grass component species, 2) application of proven turf-appropriate weed control practices during the summer, and 3) early fall planting of forbs into the established grasses. Objectives were to determine the efficacy of this grass-first planting strategy, compare transplanting vs direct seeding for forb establishment, measure the efficacy of postestablishment imazapic and pendimethalin for reducing weeds the spring after establishment, and evaluate short-term persistence and succession of grasses and forbs. Each of the 3 exercised weed control options, mowing, application of 2,4-D, or application of Ortho Weed B Gon®, resulted in successful meadow establishment under conditions of complete failure for a non-weeded, spring-planted, "common-practice" control. Fall transplanting of the forb components into established grasses was successful but seeding resulted in a greater density of forbs and an overall more aesthetically pleasing mix of flowering plants and grasses. A post-establishment application of imazapic and pendamethalin did not reduce weed density. One grass species, slender wheatgrass (Elymus trachycaulus (Link) Gould x Shinners [Poaceae]) aggressively dominated the grass stands. Five species of forb wildflowers, all from the family Asteraceae, consistently established well, persisted over the period of the study, and contributed good color to the meadow plantings; yarrow (Achillea millefolium L. [Asteraceae]), Pacific aster (Symphyotrichum chilense (Nees) G.L. Neesom [Asteraceae]), blanketflower (Gaillardia aristata Pursh [Asteraceae]), black-eyed Susan (Rudbeckia hirta L. [Asteraceae]), and Mexican hat (Ratibida columnifera (Nutt.) Wooten & Standl. [Asteraceae]). A grass-first meadow establishment protocol should be valuable where native plantings are desired for urban habitat development and beautification.

Objectives

This project is guided by four objectives:

1) Determine the efficacy of a grass-first planting strategy for meadow establishment.
2) Compare transplanting vs seeding as methods for creating long-term diversity in wildflower natural areas.
3) Evaluate the use of post-establishment herbicides for control of annual weeds.
4) Assess the persistence and contribution of grass and forb species in a wildflower planting.

Accomplishments

In lieu of a detailed description of methods and results, a copy of a paper recently submitted to the Native Plants Journal is appended (Appendix 1) to this report. The paper provides a complete report of the 3-year project.

Short summary of findings: Successful establishment of a wildflower meadow was accomplished through the use of a grass-first protocol. The strategy employed a 3-step process, 1) spring planting of grass component species, 2) application-appropriate herbicides or mowing during the summer, and 3) early fall planting of forb wildflower component species into the established grasses. Each of the 3 exercised weed control methods resulted in successful meadow establishment as compared with complete failure for a non-weeded, common-practice control. Mowing was the relatively weakest weed control method, followed by application of 2,4-D and then Ortho Weed B Gon®.

Fall transplanting of the forb components into established grasses was successful, although potentially expensive, and proved a good method for meadow completion. Transplanted forb plants were initially larger and more competitive than their seeded counterparts, and flowered the first year. However, seeding resulted in a greater density of forbs and an overall more aesthetically pleasing mix of flowering plants and grasses after 3 summers of growth.

The grass-first protocol should be a valuable tool for meadow establishment in urban and suburban sites where native plantings are desired for habitat development and beautification. The procedure was vetted under modestly controlled conditions where water and fertilizers were applied to optimize plant establishment and enhance nutrient cycling. Providing optimal establishment conditions and infusing minimal inputs of water will be necessary in arid climates such as those found in southeast Idaho if a meadow is to provide displays of season-long color.

Results of this study will be used to create a Guide for Wildflower Meadow Establishment, to be published through the University of Idaho’s Department of Educational Communications. Recommendations will be compiled for establishment protocols and for grass and forb species components adapted to local conditions.

Expenditure Report

Category	Amount Allocated	Amount Expended
Part-time wages and fringe benefits	$1,505	$ 0
Supplies (seed, pots, labels, herbicides, etc)	$ 200	$ 200
Other expenses (field charges, motor pool)	$ 350	$ 350
Total funds allocated	$2,055	
Total expensed to date		$ 550
Amount remaining as of 31 Dec 2014	$1,505	

Negotiations between ISDA and the University's Office of Sponsored Programs delayed expenditures for this grant. A no-cost extension is being requested.

Appendix 1: Draft Manuscript - Not for Distribution

Managing Weeds During Wildflower Meadow Establishment: Efficacy of a Grass-First Strategy for Sites With Heavy Annual Weed Pressure

Stephen L Love and Pamela J.S. Hutchinson

ABSTRACT:

The idea of creating attractive, sustainable wildflower meadows in private and public green spaces is becoming increasingly popular. Establishment failure rate for new meadow plantings is very high, primarily due to annual weed pressure. An establishment method based on plant succession principles and involving a 3-step, grass-first protocol for reducing weed competition consisting of, 1) spring planting of grass component species, 2) application of proven turf-appropriate weed control practices during the summer, and 3) early fall planting of forbs into the established grasses., was proposed and tested. Objectives were to determine the efficacy of a grass-first planting strategy, to compare transplanting vs direct seeding for forb establishment, to measure the efficacy of postestablishment imazapic and pendimethalin for reducing weeds the spring after establishment, and to evaluate short-term persistence and succession of grasses and forbs. Results supported the concept of a grass-first protocol. Each of the 3 exercised weed control options, mowing, application of 2,4-D, or application of Ortho Weed B Gon®, resulted in successful meadow establishment under conditions of complete failure for a non-weeded, spring-planted, “common-practice” control. Fall transplanting of the forb components into established grasses was successful but seeding resulted in a greater density of forbs and an overall more aesthetically pleasing mix of flowering plants and grasses. A post-establishment application of imazapic and pendamethalin did not reduce weed density. Seventeen grass and forb species were evaluated for persistence and contribution to meadow aesthetics. One grass species, slender wheatgrass (*Elymus trachycaulus* (Link) Gould x Shinners [Poaceae]) aggressively dominated the grass stands. Five species of forb wildflowers, all from the family Asteraceae, consistently established well, persisted over the period of the study, and contributed good color to the meadow plantings; yarrow (*Achillea millefolium* L. [Asteraceae]), Pacific aster

(*Symphyotrichum chilense* (Nees) G.L. Neesom [Asteraceae]), blanketflower (*Gaillardia aristata* Pursh [Asteraceae]), black-eyed Susan (*Rudbeckia hirta* L. [Asteraceae]), and Mexican hat (*Ratibida columnifera* (Nutt.) Wooten & Standl. [Asteraceae]). A grass-first meadow establishment protocol should be valuable where native plantings are desired for urban habitat development and beautification.

KEY WORDS:
Forb, herbicide, plant succession, augmentative restoration, urban habitat

NOMENCLATURE:
Native Species: USDA NRCS (2015)
Weed Species: Weeds of the West (2004)

CONVERSIONS:
1 sq ft = 0.093 sq m
1 lb = 0.454 kg
1 oz = 28.35 g
Seeds/kg = seeds/lb x 2.20
Seeds/sq m = seeds/sq ft x 10.75
oz/plot = grams/plot x 28.35

The concept of a mixed grass and forb native planting, often referred to as a wildflower meadow, is becoming increasingly more evident and popular as land managers attempt to restore pockets of local habitat and create more sustainable urban and suburban landscapes. Wildflower meadows are used for roadside beautification, reclamation of disturbed urban public lands, habitat establishment in parks and golf courses, and improvement of minimally-managed private property (Delaney and others 2000; Weaner 2012; Federal Highway Administration 2007; Weston 1990; Henry and others 1999; Rothenberger 2002). Potential benefits from a successful wildflower meadow planting include, soil stabilization, improved aesthetics, pollutant entrapment, habitat improvement for birds, small mammals and pollinators, reduced maintenance costs, species conservation, and opportunities for education (Aldrich 2002; Delaney and others 2000).

Common perception is that creation of a natural-looking, functional wildflower meadow is as simple as tilling a plot of ground, scattering some seeds, and letting nature take its course. Unfortunately, because this procedure ignores the principles of natural ecosystem succession and the importance of disruption by exotic weed species, the result is usually less than desirable. Recommendations for planting wildflower meadows include careful consideration and application of appropriate practices, including selection of an appropriate site, using adapted and compatible grass and forb species, site preparation, weed control, and employing effective planting methods (Perry 2005; Aldrich 2002, Delaney and others 2001; Neal and Papineau 2012). Of these factors, inadequate weed control during establishment is the most common contributor to failure Aldrich 2002; Norcini and Aldrich 2009; Perry 2005).

Issues associated with establishment of functional wildflower meadows are similar to those associated with wildland restoration. Adherence to proven restoration principles and protocols may improve the chances for successful meadow establishment. Madsen and others (2013) listed these major barriers to successful sagebrush steppe restoration: 1) water availability, 2) crusting soils, 3) plantability of small-seeded species, 4) control of seed germination, 5) seed-soil contact, and 6) competition from weeds. In an urban or suburban meadow planting, most of these barriers are easily managed through the use of irrigation, selection of appropriate component species, and proper planting techniques. Weed control remains as the single major barrier to initial establishment.

Models involving plant succession are becoming prominent in restoration science (Bard and others 2004; Bradshaw 1996; McLendon and Redente 1990; Sudig and others 2004; Walker and del Moral 2008). Plant succession is defined as changes in vegetation following natural or human-caused disturbance, eventually resulting in a stable, climax plant community (Roundy 2005). Succession-based restoration involves the idea of managing aspects of plant communities over a long period of time to take advantage of existing plant assemblies while allowing time for establishment of pre-existing nutrient cycles and plant interactions. Primary succession occurs when vegetation begins to grow on a site where a plant-based ecology never existed. Secondary succession occurs where elements of a pre-existing ecology remain intact after a disruptive event. Walker and del Moral (2008) suggest that restoration of abandoned agricultural fields, akin to most planting sites for wildflower meadows, is more representative of primary than secondary succession due to the extended period of disruption. Knowledge of succession and its constituent processes may help us ameliorate establishment issues.

Bomberger and others (1983) suggested that succession toward a pre-existing state in a tall-grass prairie on an old field site in Nebraska would require more than 40 years and ultimate species composition may still be altered. A breakdown of the succession timeline suggested 1 to 2 years of ruderals and annual pioneer weeds, 1 to 13 years of annual grasses, 10 to 20 years of perennial bunchgrasses, and ultimately a mixed population of grasses, forbs, and occasional woody species. Succession in any plant community assumes the presence of seed sources for the climax species. In urban and suburban sites a complete lack of climax species in the seed bank means the first successional stage made up of ruderals and annual weeds will be repeated in an unending cycle of germination, growth, and seed production. As a result, the bank of annual weed seeds in these sites is very high, creating highly competitive conditions for newly planted meadow component species.

Published suggestions for controlling aggressive annual weeds prior to and during meadow establishment include pre-planting of a competitive green manure crop, irrigation followed by tilling just prior to planting, soil solarization, removal and replacement of topsoil (impractical), mulching, use of herbicides, and mowing (Aldrich 2002; Delaney and others 2001, Holt 2004). Some of these methods are effective in reducing or eliminating weeds present prior to planting meadow components, but all have limitations in controlling weeds that emerge simultaneously with the desirable seedlings and jointly compete for light and resources. Burnside and others (1996) and Conn and others (2006) found that seeds of many common weeds remain viable in the soil for 10 years or more. The implication is that a year or two of pre-planting weed control will do little to alleviate competition and enhance meadow establishment success, especially in weed-prone urban and suburban sites.

Porensky and others (2014) found that established native perennial grasses suppressed weed growth during restoration of arid, old-field sites in Nevada. Established, late-successional tall-grass prairie plantings were found by Blumenthal and others (2003) to reduce weed biomass by 94% in comparison with adjacent non-restored sites. This implies that meadow plantings, once successfully established and mimicking late-successional status can become invasion-resistant and be successful in the long term. The work of Porensky and others (2014) also suggests that pre-establishment of grasses prior to planting of forb species is a potential mechanism for successful establishment of wildflower meadows under conditions of a heavy annual weed seed bank. The idea of grass-first establishment combines the primary succession concept of Walker and del Moral (2008) for old agricultural sites with the idea of augmentative restoration presented by Bard and others (2004).

Lack of appropriate species selectivity limits the value of herbicides for meadow weed control. Regardless, herbicides are being employed to enhance native plant stands during restoration projects (Bahm and Barnes 2011; Baker and others; Bekedam 2005; Benson and others). Among the postemergence herbicides tested for weed control in native plants are imazapic (Plateau®) and pendimethalin (Prowl H2O®) (Bahm and Barnes 2011; Baker and others 2009; Davies and Sheley (2011); Wiese and others 2011). Applied post-emergence, these products tended to damage or kill seedlings but produce only minor injury on large, established plants (Davies and Sheley 2011; Wiese and others 2011; Bahm 2011; Morishita and others 2011). Therefore, imazapic and pendimethalin applied during the late establishment phase of a meadow may reduce ultimate weed density.

Transplanting, as opposed to direct-seeding, can be an effective method to overcome establishment barriers encountered during native plant restoration projects (Sheley and others 2008). Published meadow planting guides often make reference to the advantages of transplanting meadow elements, but no research is cited to support the concept (Aldrich 2002; Delaney and others 2000; Perry 2005). Transplanting forb components of a meadow may provide advantages for establishment and advancement of early succession.

Choice of grass and forb species used as components in a wildflower meadow will determine long-term successive development and aesthetic value (Pywell and others 2003). In a recent study, Pywell and others (2003) found the most important performance traits of species for restoration communities in the UK to be broad adaptation, resistance to stresses, competitiveness (vigor, height, etc.), high levels of seed production, and seed bank persistence. Research is lacking to identify suitable grass and forb components for wildflower meadow plantings in the arid, high desert regions of the northern Intermountain West.

Research objectives for this study were 4-fold: 1) determine the efficacy of a grass-first strategy for wildflower meadow establishment, i.e. planting grass components first, followed by mowing and herbicide treatments for initial weed control, and finalized by seeding or transplanting forbs into the established grass stands; 2) compare transplanting and direct seeding as tools to optimize species establishment and aesthetic value in a wildflower meadow, 3) test the efficacy of a spring, postemergence application of the herbicides imazapic and pendimethalin for reducing second-year weed density in established plots, and 4) evaluate short-term persistence and succession of grass and forb species components in the context of a wildflower meadow planting.

METHODS

The meadow establishment study was conducted 2013 through 2015 at the University of Idaho's Aberdeen Research and Extension Center, Aberdeen, Idaho. The Center is located on the Snake River Plain in the southeastern region of the state.

Site Description: Climate at the study location is arid high desert, annual precipitation 234 mm (9.2 in), an average July high temperature of 30.5°C (87°F), an average January low temperature of -11°C (12°F), with USDA Plant Hardiness Zone equivalent to 4. Soil type in the study field is a Declo silt loam (course-loamy, mixed, superactive, mesic, xeric, haplocalcid) with pH 8.2, 1.02% organic matter, and relatively low fertility levels. The trial area was located on the site of an old abandoned homestead. Native grasses and forbs were absent from the site, the soil weed seed bank high and persistent, and annual weed pressure historically high and consistent.

Site Preparation: On 17 Jun 2013, the entire trial area was sprayed with a 3% solution (acid equivalent) of glyphosate (Roundup®, Monsanto Corp.) using a backpack sprayer at 2.1 kg sq cm^{-1} (30 psi) and a water carrier volume of 140 l/ha (15 gal/A) to control existing stands of perennial weeds. On 26 Jun 2013, the plot area was tilled with a rotovator to produce a clean seedbed. On 11 Jul 2013, two weeks after the initial planting date (see below), the entire plot area was fertilized using a broadcast generic 30-0-3 product at a relatively low rate equivalent to 44.8 kg/ha (40 lb/A).

Meadow Species Component Seed Mixes and Transplants: Seeds of 17 adapted and potentially adapted native plant species, 5 grasses and 12 forbs, were purchased from Western Native Seed (Coaldale, CO). Table 1 lists species selected and their individual seed characteristics. NRCS recommendations from the Las Lunas Plant Materials Center for seeding grasses in semi-arid ecoregions was used as a basis for seeding rates in the study (Dreesen). Seeds were combined to create two separate seed mixes, one for grasses and the other for forbs. Calculations for the mixes were based on target composite seeding rates of 538 pure live seed (PLS)/m^2 (50 PLS/ft^2) for the 5 combined grass species and 517 PLS/ m^2 (48 PLS/ft^2) for the combined 12 forb species.

Transplants of the 12 forb species used in the study were produced in a greenhouse at the Aberdeen R & E Center. Seeds of western larkspur and the two penstemon species were stratified for 3 weeks prior to planting. Seeds of all 12 species were seeded into flats mid-July. After emergence, seedlings with 2 to 5 true leaves were teased out of flats, transplanted into 7.6 cm x 12.7 cm (3 in x 5 in) pots (Thermoform®, A.M. Leonard, Piqua, OH), and allowed to grow until the designated field transplanting date. Transplants were between 3 cm (1.2 in) and 10 cm (3.9 in) tall, depending on species, at the time they were transplanted to the field.

Plot Design: Plots were arranged in a randomized complete block design with 3 replications. Individual main plots were 37.2 m^2 (400 ft^2) with dimensions of 6.1 m x 6.1 m (20 ft x 20 ft). In the spring of 2014, main plots were divided into 2 randomized subplots to allow for application of imazapic and pendamethalin herbicides thus creating a split plot statistical design.

Experimental Treatments: The study consisted of 8 main-plot treatments, including 2 controls (Table 2). The first control provided a comparison of common-practice meadow-establishment procedures (till, broadcast seed, anticipate growth). The second control provided a comparison with optimal establishment conditions (till, plant grass, complete weed control by hand-weeding, over-seed forbs in fall). The other 6 test treatments were a factorial arrangement of 3 weed control treatments (mowing, 2,4-D herbicide, Ortho Weed B Gon® herbicide) and 2 forb-establishment techniques (seeding or transplanting). In all 6 test treatments, grasses were seeded in the spring, weed control options were employed on a predetermined schedule, and forb components were added to the plots in early fall after the grasses were fully established and some modicum of weed control was evident.

The mowing treatment started when the vegetation in the plots was about 10.1 cm (4 in) tall, continued through the summer, and ceased when the forb components were added to the plots. Plots were mowed twice per week and mowing height was maintained at 6.4 cm (2.5 in) throughout the treatment period.

Single applications of 2,4-D (Hi-Yield 2,4-D amine, VPG Fertilome, Bonham, Texas) and a Ortho Weed B Gon® (mecoprop-p dimethylamine salt 5.30% + 2,4-D, dimethylamine salt 3.05% + dicamba, dimethylamine salt 1.30%, The Scotts Miracle-Gro Company, Marysville, Ohio) were made July 26 at 2.3 l/ha (2 pints/A) product and 9.1 l/ha (7.8 pints/A) product, respectively, with a backpack sprayer at 2.1 kg/cm^2 (30 psi) and a water carrier volume of 140 l/ha (15 gal/A). Grass seedlings were visible and weed vegetation in the plots was approximately 10.1 cm (4 in) tall at application time.

On 17 Apr 2014, the spring after all grass and forb components were seeded or transplanted, a tank mix of imazapic (Plateau®, BASF, Ludwigshafen, Germany) and pendamethalin (Prowl H_2O®, BASF, Ludwigshafen, Germany) was applied to a random half of each main plot while vegetation was dormant or in the early green-up phase. Application rates were 59 ml/ha (2 oz/A) imazapic and 2.1 l/ha (1.8 pints/A) pendamethalin made with a backpack sprayer as previously described.

Planting and Maintenance: The grass and forb mix in the common-practice control and grasses in the remainder of the treatments were seeded on 28 Jun 2013 (Figure 1). Seeds were broadcast by hand across each plot at rates listed in Table 1 and the soil lightly raked to incorporate the seeds to a depth of about 6.4 mm (0.25 in). Plots were sprinkler irrigated daily with approximately 0.64 cm (0.25 in) day for 10 days after planting to maintain a damp soil surface; after which irrigation was continued with weekly water applications of approximately 12.7 mm (0.5 in). Note: irrigation was with-held for three days before and after herbicide treatments were applied.

For the seeded treatments, forb component species were planted into the established grass stands (some weeds present) on 28 Aug 2013. Figures 2 through 6 illustrate the status of weed control in the plots at the time the forbs were planted. Seeds were broadcast by hand and the plots raked carefully to limit damage to established plants. On the same date, greenhouse-grown potted forbs were planted into the transplant plots. Ten plants each of yarrow, purple prairie clover, Pacific aster, James' buckwheat, blanketflower, blue flax, Munro's globemallow, black-eyed Susan, and Mexican hat, plus 5 plants of firecracker penstemon were randomly (but uniformly) placed and installed within each plot. Insufficient plants of firecracker penstemon emerged in the greenhouse to provide a full 10-plant complement; therefore, only 5 plants each of these two species were placed in each plot. Rocky Mountain penstemon and western larkspur did not emerge in the greenhouse and were not included in the transplant mix. A total of 95 forb plants were transplanted into each plot, considerably fewer than the approximately 39,200 total live seeds scattered into the seeded plots. Determination of the number of transplants to employ was based on our interpretation of practicality.

After the August 2013 forb seeding and transplanting was completed, plots were irrigated daily for 10 days with approximately 0.64 cm (0.25 in) to maintain a damp seed and root zone. After the initial 10 days, the summer irrigation schedule was resumed until mid-October when irrigation was terminated. During the summers of 2014 and 2015, once the plants were fully established, the plots were irrigated once every 10 days with 25 mm (1 in) of water per application. Each year, during the last week of October, all plots were mowed down and the litter chopped and left on the soil surface.

Data Collection: In mid-October (16 Oct 2013) of the establishment year, visual estimates of ground cover for grasses, wildflowers (forbs), and weeds were recorded. In 2014 (completed 24 Jun) and 2015 (completed 17 Jul), plant counts within a single randomly positioned meter-square quadrat were made to provide an estimate of species density within each sub-plot, with separate counts for grasses, wildflowers, and total weeds. Final data collection in 2015 included a subjective aesthetic value score and whole-plot counts of wildflower forbs, separated by species.

Data Analyses: The study was designed to allow a stepwise analytical process. The first step was to employ a simple RCBD analysis of variance of the ground cover estimates taken at the end of the establishment year. The second step was to complete a split-plot RCBD analysis of variance to determine the statistical significance of the effect of the spring 2014 imazapic plus pendimethalin application compared with no application in the sub-plots. The pre-determined strategy was to maintain this variable in subsequent analysis if it was significant for any of the measured variables but if not significant drop the sub-plot analysis and average the sub-plot measurements.

The third analytical step was to complete an analysis of variance for a data set that included the two control treatments and the 3 seeded weed-control treatments in order to determine the statistical and biological significance of the mowing, 2,4-D, and Weed B Gon® treatments. The fourth analytical step involved dropping the control treatments from the data set and completing a factorial analysis of variance to explore the treatment effects and interactions of the weed control and planting method treatments.

All analyses were completed using PROC ANOVA in the SAS (SAS Institute, Cary, North Carolina) statistical program. Means separations were made using Fischer's least significant difference test (LSD).

RESULTS

Good stands of both grasses and forbs (in the common-practice control) were evident in all plots following spring planting. Weeds emerged in very high numbers at the same time as the meadow species in all plots and almost immediately began competing. Forbs planted August 2013 into stands of established grasses, wherein some level of weed suppression or control had been achieved, were also successfully established. Consistent, uniform stands of forb seedlings were observed in the seeded plots and overall survival of transplants when estimated a few weeks after planting was over 90%.

Visual ground cover estimates taken in October of the establishment year (2013), almost 2 months after planting forbs into the grass-first plots, provided a good measure of initial planting success and impact of early weed competition in the plots (Table 3). Analysis of variance, completed as a first analytical step across all 8 treatments, revealed significant treatment differences for grass cover (*Prob.>F* <0.01), forb cover (*Prob.>F*<0.01), and weed cover (*Prob.>F*<0.01). Weed cover in the common-practice control was near 100% and resulting heavy competition eliminated nearly all meadow species plants by the end of the establishment year. With few exceptions, grass and forb plants that did survive were along the edges of plot alleys where competition was artificially reduced. Weed cover in the hand-weeded control treatment was 14%, indicating a certain level of weed reestablishment after hand-weeding ceased on 28 Aug 2013. Weed cover in the mowing treatment was less than for the common-practice control, but still relatively high compared to the herbicide treatments.

Transplanting resulted in greater forb groundcover than did seeding, even though plant density in the seeded plots was much higher; the result of the tranplants being considerably larger than the seedling counterparts since transplanting and seeding occurred on the same day.

The second analytical step was evaluation of the efficacy of the spring 2014 post-emergent herbicide treatments (imazapic plus pendamethalin). This herbicide treatment did not reduce weed density compared with density in the adjacent non-treated split plots (*Prob.>F*=0.16). The spring 2014 herbicide treatment also had no impact on the density of meadow-component grasses (*Prob.>F*=0.90) or forbs (*Prob.>F*=0.97). Visual inspection of the plots in the spring of 2014 revealed that the weed composition in the split plots was slightly different, with a relative reduction in the annual mustard species in the treated plots. This slight shift in composition did not translate to a significant reduction in weed density or in visible weed competition. Given the lack of response to the spring 2014 postemergence herbicide application, the plant density values within each split plot were averaged for each main plot and the split plot analysis removed from subsequent statistical models.

The third analytical step was to remove the transplanting treatments from the data set in order to evaluate only the seeded treatments for best comparison of applied weed control options against the controls (both of which were seeded). Data from each evaluation year (2014 and 2015) were analyzed and presented separately because they represented two different stages in succession of the meadow plantings (Table 4). In 2014, there were significant treatment effects for grass density (*Prob.>F*<0.01) and weed density (*Prob.>F*<.01). Visibly, there was a distinct difference in forb presence, at least between the treated plots and the common-practice control, however, the treatment effect on forb density (*Prob.>F*=0.18) was not statistically significant. This last result was likely due to variability in the data created by a lack of uniformity in forb distribution that our sampling methods did not resolve. This meant we could not derive any conclusions about the success of forb establishment from the 2014 data set.

Other than a difference between the common-practice control and all weed control treatments, there were no differences in weed density among treatments, including the hand-weeded control. Weed density in the common-practice control plots was 1,145/ m^2 (106/ft^2) compared to weed density in the hand-weeded control and other treatments which ranged from 11 to 45 weeds/ m^2 (1 to 4.2/ft^2). All of the grass-first weed control treatments had a positive impact on establishment of the grass meadow components (Table 4). The highest density of grasses occurred as a result of the Ortho Weed B Gon® treatment; followed by grass density in the 2,4-D and mowing treatments, and all had greater grass density than being the common-practice control. These data reflected only the absence or presences of grasses in the plots. Visually, the most robust grass plants were located in the hand-weeded control plots, then - seemingly related to relative weed density reduction - from most to least robust, Ortho Weed B Gon®, > 2,4-D > mowed plots (Figures 2 through 6). Grass plants in the mowed plots had visually apparent competition from weeds and were slender and small in stature. It should be noted that the grass density in the hand-weeded control may have been artificially low because of damage to and accidental removal of seedlings during the hand-weeding process.

In 2015, compared with the year before, the average weed density in the common-practice control treatment was about half as great as in 2014. Weed density in the treated grass-first plots, on average, changed very little. Surprisingly, although the weed density in the common-practice control was much greater than in the grass-first plots, there was no significant difference in weed density between any of the treatments. Lack of significance was the result of variability created by differential succession in the plots. Weed density in many of the plots declined dramatically, while changing very little in others. In one of the common-practice control plots, weed numbers were almost as low in the grass-first plots while density in other plots within the control treatment remained almost as high as in 2014.

Forb density generally tended to increase slightly from 2014 to 2015, but statistically there were again no significant differences among treatments. This result was not surprising given the 2014 results.

In 2015, an aesthetic value rating was added to the data set (pictorially illustrated in Figures 7 through 12). This subjective rating was designed to reflect the inherent attractiveness of the established meadow in the case of each treatment. The highest aesthetic value scores (highest rating=10) were given to plots with the fewest weeds, a visible balance between grasses and flowering forbs, and a pleasing palette of color. All of the grass-first treatments had higher aesthetic value ratings than the common-practice control. No significant differences in aesthetic value existed among the mowing and herbicide treatments.

The final analytical step involved a factorial ANOVA on a data set with the two control treatments removed. This analysis was designed to increase sensitivity for detecting differences between the weed control methods and planting methods and to allow exploration of the interaction between these two variables (Table 5). No significant interaction was detected between weed control methods and planting methods for any of the variables measured. Subsequently, the main effects were analyzed.

Weed, grass, and forb densities were statistically similar across all weed control methods for both evaluation years (Table 6). A high but non-significant weed density mean for the 2,4-D treatment was due to a single, spurious value resulting from an unusual number of weeds in a single plot. Planting method had no influence on grass or weed density. Forb density was significantly lower both years in the transplanted vs seeded treatments (Figures 9 and 10). Given the lower initial planting density in the transplanted plots, this was an expected result. Weed control method did not have a significant effect on the final aesthetic value rating, although planting method did. The lower number of forbs, associated with fewer flowers and color elements in the plots, resulted in lower aesthetic value ratings for the transplanted plots in comparison with the more attractive seeded plots.

Unique responses were observed for each of the grass and forb species components included in the study. Although no attempt was made to statistically analyze the establishment and survival trends for the different species, we felt presentation of the data might prove valuable in showing species response patterns and meadow component contributions (Table 7). Of the 5 grass species, 4 successfully established in the plots; Idaho fescue, big bluegrass, and slender wheatgrass. Slender wheatgrass emerged in relatively high numbers, grew rapidly, was tall at maturity, and ultimately developed very dense stands. As a result, this one grass species tended to out-compete the other grass species and visibly dominated the meadow plantings.

Of the 12 forb species, 5 established well, competed adequately with weeds and other meadow components, and contributed visible color to the plots: yarrow, Pacific aster, blanketflower, black-eyed Susan, and Mexican hat (Table 7). Two additional species, blue flax and Munro's globemallow, were present in the plots in low numbers. Purple prairie clover, James' buckwheat, and firecracker penstemon did not successfully establish in the seeded plots. These three species were successfully transplanted but disappeared over the two years of evaluation due lack of competitiveness. As mentioned, Western larkspur and Rocky Mountain penstemon seeds failed to emerge either in the field or in the greenhouse flats during transplant production and these species were entirely absent from the study plots.

Notes documenting the presence and relative abundance of weed species were recorded each year, providing the ability to track succession shifts as the meadow plantings began to mature. During the early summer of 2013, just after planting of the grass species, 4 weeds species predominated in the plots; common purslane (*Portulaca oleracea* L. [Portulacaeae]) was by far the most prominent and problematic weed, but also present and competitive were kochia, (*Kochia scoparia* (L.) Schrad. [Chenopodiaceae]) redroot pigweed (*Amaranthus retroflexus* L. [Amaranthaceae]), common lambsquarter (*Chenopodium album* L. [Chenopodiaceae]) and blue mustard (*Chorispora tenella* (Pall.) DC. [Brassicaceae]). Several other annual - and a few perennial - weed species were present in smaller numbers. In an expression of early succession, by the middle of the third summer (2015), common purslane and redroot pigweed had almost completely disappeared from all plots. Kochia was rare, except along plot borders, in plots with well-established and competitive meadow components. Blue mustard remained present only where small, open non-competitive spaces were present. Kochia continued to dominate the common-practice control plots where meadow species were meager or non-existent. In plots where meadow species were competitive, weeds as a whole were relatively sparse and the species distribution shifted from the most aggressive early colonizers to seemingly less aggressive second-generation succession annuals such as prickly lettuce (*Lactuca serriola* L. [Asteraceae]), flixweed (*Descurainia Sophia* (L.) Webb. ex Prantl [Brassicaceae]), western salsify (*Tragopogon dubius* Scop. [Astereaceae]), and tumble mustard (*Sisymbrium altissimum* L. [Brassicaceae]).

DISCUSSION

Failure of wildflower meadow plantings is apparently a common occurrence, with the primary cited reason being lack of proper weed control during establishment (Aldrich 2002; Norcini and Aldrich 2009; Perry 2005). Many techniques recommended for weed control during wildflower meadow establishment involve attempts to manage the weed seed bank and thereby reduce initial competition for grass and forb seedlings (Aldrich 2002; Delaney and others, 2000; Sheley and others 2008). Realistically, the weed seed bank in many historically disturbed sites is uncontrollable as a result of seed abundance and seedbank longevity (Burnside and others 1996; Conn and others 2006). Rather than try to control or eliminate the seed bank, it makes more sense to employ an ecologically sound methodology to augment succession and rapidly advance a habitat beyond initial ruderal stages.

In this study, the inclusion of what we referred to as the “common-practice” control succinctly demonstrated the weakness of typical meadow establishment protocols consisting of spring site preparation, pre-plant weed control, and single-step broadcasting of a grass and forb seed mix. In spite of excellent emergence and early seedling growth for the meadow component species, aggressive annual weeds quickly out-competed desirable seedlings in our study, and by the end of the first summer, virtually eliminated all perennial grass and forb species. Over the two subsequent evaluation years, the common-practice control plots remained as “weedy patches”, locked into a static, repetitive cycle of annual weed growth. There was some evidence of succession among weed species by the end of the third year in some control plots, with purslane and redroot pigweed supplanted by prickly lettuce and annual mustards. But there was no progression toward a stable meadow habitat due to a lack of competitive perennial climax species. In contrast, a grass-first establishment protocol, employed as part of an augmentative restoration process (Bard and others 2004), resulted in successful establishment of meadow species and rapid advancement toward a climax habitat.

Some interesting insights related to effective meadow establishment emerged from this study. For instance, based on grass and forb response to weed species and densities in our study, we reached the conclusion that complete weed control is apparently unnecessary for successful establishment of meadow component species. Degree of weed control during the establishment year varied widely across treatments, with hand-weeding providing the best control, followed by applications of Ortho Weed B Gon® and 2,4-D, and finally mowing. Weed B Gon®, a pre-mix of 2,4-D, dicamba, and mecoprop, provided visibly better weed control than 2,4-D, resulting in more bare soil area in the plots at the time the forbs were planted in Aug 2013 (Figures 2 through 6), but this difference in weed pressure tended to diminish by the time the ground cover estimates were made October 2013 (Table 3). Mowing did not kill weeds, especially the low-growing purslane, and a thick carpet of short vegetation was present during the establishment season. However, mowing kept the weeds sufficiently short that meadow components were not terminally outcompeted for light, water, and other resources. Regardless of the weed control method employed, meadow establishment was successful. The presence of weeds, and the amount of weeds successfully reseeding during the establishment year, did not seem to make a difference as to the weed density by the end of the third summer. The important factor appeared to be the presence and vigor of the perennial meadow component species, especially the grass species, a deduction that conforms to the findings of Blumenthal and others (2003).

An observation not clearly presented in the results, but evident from Table 3, was the limitation of forb establishment as a result of competition from the grass components. Treatments that provided the best weed control also produced the most vigorous grass plants, with a secondary effect of limiting ultimate density of wildflower forbs. In some of the plots, especially those hand-weeded or treated with Ortho Weed B Gon®, forb density was quite low in spite of excellent weed control. Grass competitiveness is an issue that can be controlled through species choice and seeding rates and should not present unsurmountable problems for adoption of a grass-first establishment protocol.

Pre-study expectations were that transplanting would prove to be a superior establishment tool in comparison to seeding. Pywell and others (2003) evaluated commonly used species for traits associated with superior performance in restoration plantings, among them stress tolerance, vigor, competitiveness, and seed production. Logically, transplants should provide some of these same advantages as a result of culture - plant size and phenology - rather than genetics. During the establishment season, transplanted forbs did appear to outperform their seedling counterparts in many respects. They expressed very high rates of initial survival, seemed to be more competitive with the grasses and weeds, bloomed the first year, and produced seed earlier; seed that could potentially contribute to recruitment. But expectations did not bear out in our study since recruitment did not appear to be important in meadow establishment nor in advancement succession during the first 3 years covered by our study. Forb densities in the third summer (2015) and the related aesthetic value ratings were much higher in the seeded treatments than the transplanted treatments; logically not surprising given the much higher seeding rate and good seed establishment conditions. Under less optimal growing conditions, transplanting may prove to more efficacious.

Competitiveness and successful establishment varied widely amongst the 17 species included in this study. Slender wheatgrass emerged at a high rate, was rapid growing and competitive, and very quickly came to dominate the spring-planted grass stands. Depending on the objective for a meadow planting, this species may be too tall and aggressive to allow optimal grass/forb ratios in a mixed grass and forb planting. However, slender wheatgrass very effectively suppressed annual weeds and helped advance succession in the plots. Idaho fescue and big bluegrass emerged well and were present in the plots at the end of the third summer. These two species may be good meadow components when mixed with less competitive companions. Indian ricegrass and tufted hairgrass never presented themselves within the plots except for an occasional plant.

The best performing wildflower forbs in the plots, based on survival, competiveness, and contribution of color were yarrow, Pacific aster, blanketflower, black-eyed Susan, and Mexican hat. Interestingly, all of these species are large-statured prairie plants from the family Asteraceae. Each of these species, by and large, exhibit the traits listed by Pywell and others (2003) as being essential to consistent performance in ecological restoration. Blue flax and Munro's globemallow showed a limited but consistent presence in the plots. As seedlings, these species seemed to have a hard time competing with faster growing plants, but competed adequately when mature. James' buckwheat and firecracker penstemon were not able to successfully compete in these meadow plantings as evidenced by the disappearance of transplants from the plots after showing a high rate of survival at the end of the establishment year. Western larkspur and Rocky Mountain penstemon seeds did not emerge, either in the plots or the greenhouse. Given past experience with *Delphinium* species, recalcitrance in the larkspur is not surprising. However, expectations were that Rocky Mountain penstemon would perform better, suggesting the seed lot may have had seed viability issues. Even with viable seed, it may be that the planting schedules employed in this study would favor establishment of species that do not require vernalization, a possible hindrance to a species such as Rocky Mountain penstemon.

CONCLUSIONS AND APPLICATION

Successful establishment of a wildflower meadow was accomplished through the use of a grass-first protocol. The strategy employed a 3-step process, 1) spring planting of grass component species, 2) application-appropriate herbicides or mowing during the summer, and 3) early fall planting of forb wildflower component species into the established grasses. The expectation was that this 3-step approach would mimic augmented and enhanced plant succession under our initial site conditions of native species paucity and very high annual weed pressure.

Each of the 3 exercised weed control methods, mowing, application of 2,4-D, or Ortho Weed B Gon® resulted in successful meadow establishment compared with the complete failure for a non-weeded, common-practice control. Mowing relatively weakest weed control, method, followed by application of 2,4-D and then Ortho Weed B Gon®; but all three methods allowed meadow components to be sufficiently competitive to survive during the all-important first summer.

Fall transplanting of the forb components into established grasses was successful, although potentially expensive, and proved a good method for meadow completion. Transplanted forb plants were initially larger and more competitive than their seeded counterparts, and flowered the first year. However, seeding resulted in a greater density of forbs and an overall more aesthetically pleasing mix of flowering plants and grasses after 3 summers of growth.

The grass-first protocol should be a valuable tool for meadow establishment in urban and suburban sites where native plantings are desired for habitat development and beautification. The procedure was vetted under modestly controlled conditions where water and fertilizers were applied to optimize plant establishment and enhance nutrient cycling. Providing optimal establishment conditions and infusing minimal inputs of water will be necessary in arid climates such as those found in southeast Idaho if a meadow is to provide displays of season-long color. Consequently, these study results are applicable for the intended urban enhancement uses. Less clear is whether a grass-first strategy will provide the same efficacy under drier, minimally managed conditions.

ACKNOWLEDGEMENTS

Thanks to Ben Pierce for his diligent maintenance of the research site and timely data collection; to Tina Miera, Brenda Kendall, Tenika Trevino, and Jill Yancey for timely assistance with plot preparation, planting, and weeding; and to Brent Beutler for professional assistance with herbicide applications. This research was funded by grants from the Idaho State Department of Agriculture Nursery, Landscape, and Floral Program and by USDA Hatch Funds.

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Table 1. Common names, scientific names, seed weights, seeding rates, and pure live seed (PLS) weight planted in each plot for 17 native grass and forb species used as components in a meadow seed mix. Seeds weights (seeds/lb) and seeding rates (pure live seed [PLS]/ft^2) are given in English Standard units for purposes of common usage.

Common Name	**Scientific Binomial/Authors**	**Seed Weight**	**Seeding Rate**	**PLS g/plot**[z]
Grasses		#/lb	PLS/sq ft	
Idaho fescue	*Festuca idahoensis* Elmer [Poaceae]	425,000	10	4.4
Indian ricegrass	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth [Poaceae]	141,000	10	13.1
Big bluegrass	*Poa secunda* J. Presl [Poaceae)]	925,000	10	2.4
Slender wheatgrass	*Elymus trachycaulus* (Link) Gould x Shinners [Poaceae]	159,000	10	13.3
Tufted hairgrass	*Deschampsia caespitosa* (L.) P. Beauv. [Poaceae]	1,300,000	10	1.5
Forbs				
Yarrow	*Achillea millefolium* L. [Asteraceae]	2,700,000	4	0.3
Pacific aster	*Symphyotrichum chilense* (Nees) G.L. Neesom [Asteraceae]	800,000	4	1.1
Purple prairie clover	*Dalea purpurea* Vent. [Fabaceae]	293,000	4	2.6
Western larkspur	*Delphinium x occidentale* (S. Watson) S. Watson [Ranunculaceae]	500,000	4	2.2
James' buckwheat	*Eriogonum jamesii* Benth. [Polygonaceae]	400,000	4	6.1
Blanketflower	*Gaillardia aristata* Pursh [Asteraceae]	132,400	4	6.5
Blue flax	*Linum lewisii* Pursh [Linaceae]	295,000	4	2.6
Rocky Mountain penstemon	*Penstemon strictus* Benth. [Scrophulariaceae]	692,000	4	1.6
Firecracker penstemon	*Penstemon eatonii* A. Gray [Scrophulariaceae]	600,000	4	1.8
Black-eyed Susan	*Rudbeckia hirta* L. [Asteraceae]	1,575,000	4	0.6
Mexican hat	*Ratibida columnifera* (Nutt.) Wooten & Standl. [Asteraceae]	1,200,000	4	0.9
Munro's globemallow	*Sphaeralcea munroana* (Douglas) Spach [Malvaceae]	750,000	4	1.9

[z]Percent pure live seed in each seed lot derived from vendor's certification tags.

Table 2. Description of 8 experimental main-plot treatments designed to test the efficacy of a grass-first establishment protocol and the potential advantage of forb transplantation. A third variable, second-spring herbicide (imazapic and pendamethalin) application was imposed over the 8 treatments, resulting in 16 total split-plot treatments.

Treatment	**Treatment Description**
Common-practice Control	Designed to duplicate typical meadow establishment procedures. A mixture of grass and forb species seeded into a clean June seed bed. No weed control methods employed other than late fall mowing.
Hand-weeded Control	Designed for optimal establishment conditions. Grass species seeded into a clean June seed bed. Weekly hand-weeding employed to eliminate weed competition. Forb species seeded into the established grass stands in August.
Mowed & Seeded	Designed to test mowing for weed control plus seeding for forb establishment. Grass species seeded into a clean June seed bed. Weekly mowing at a 6.4 cm (2.5 in) height to reduce weed competition. Forb species seeded into grass/weed stands in August.
Mowed & Transplanted:	Designed to test mowing for weed control plus seeding for forb establishment. Grass species seeded into a clean June seed bed. Weekly mowing at a 6.4 cm (2.5 in) height employed to reduce weed competition. Forb species transplanted into grass/weed stands in August.
2,4-D Herbicide Application & Seeded	Designed to test a single 2,4-D herbicide application for weed control plus seeding for forb establishment. Grass species seeded into a clean June seed bed. 2,4-D applied in July when grasses were about 10.1 cm (4 in) tall. Forb species seeded into grass/weed stands in August.
2,4-D Herbicide Application & Transplanted	Designed to test a single 2,4-D herbicide application for weed control plus seeding for forb establishment. Grass species seeded into a clean June seed bed. 2,4-D applied in July when grasses were about 10.1 cm (4 in) tall. Forb species transplanted into grass/weed stands in August.
Weed B Gon® Herbicide Application & Seeded	Designed to test a single Ortho Weed B Gon® herbicide application for weed control plus seeding for forb establishment. Grass species seeded into a clean June seed bed. Herbicide was applied when grasses were about 10.1 cm (4 in) tall. Forb species seeded into grass/weed stands in August.
Weed B Gon® Herbicide Application & Transplanted	Designed to test a single Ortho Weed B Gon® herbicide application for weed control plus seeding for forb establishment. Grass species seeded into a clean June seed bed. Herbicide applied when grasses were about 10.1 cm (4 in) tall. Forb species seeded into grass/weed stands in August.

Table 3. Visual estimate of ground cover at the end of the establishment year for grass and wildflower meadow components and for weeds in 2 control and 6 treated plots on 16 Oct 2013. The grass and forb (wildflower) mix for the common-practice control and the grasses for the hand-weeded and weed control grass-first treatments were seeded 28 June 2013. Forbs for the grass-first treatments were seeded or transplanted on 28 Aug 2013. Mowing in the mowed treatments occurred bi-weekly during the establishment year 2013 and herbicides were applied Jul 2013.

	Grass	**Forb**	**Weed**
Treatment	**-----------------% groundcover --------------**		
Common-practice control	< 1	< 1	99
Hand-weeded control	45.0	3	14
Mowed - Seeded	12	1	75
Mowed - Transplanted	15	4	63
2,4-D - Seeded	33	1	30
2,4-D - Transplanted	17	3	13
Weed B Gon® - Seeded	35	2	28
Weed B Gon® – Transplanted	42	7	17
LSD (0.05)	16	2	15

Table 4. Density of grasses, forbs, and weeds for the seeded establishment treatments on 24 Jun 2014 and 17 Jul 2015. A grass-forb mix in the common-practice control and grasses in the grass-first treatments were seeded on 28 June 2013. Forb components were seeded into the grass-first treatments on 28 Aug 2013. Mowing for the mowed treatment occurred bi-weekly during the establishment year 2013 and herbicides were applied Jul 2013. Aesthetic value was rated only in 2015 on a subjective 1 to 10 scale with 10=best.

Treatment	Grasses	Forbs	Weeds	Aesthetic Rating
2014	------------------ # plants /m^2 --------------------			
Common-practice control	1	1	1,145	-
Hand-weeded control	14	3	11	-
Mowed - Seeded	14	3	45	-
2,4-D - Seeded	18	4	36	-
Weed B Gon® - Seeded	23	7	14	-
LSD (0.05)	8	NS	313	-
2015				
Common-practice control	0	1	545	1.8
Hand-weeded control	4	9	40	6.2
Mowed - Seeded	14	6	33	7.5
2,4-D - Seeded	14	5	16	7.2
Weed B Gon® - Seeded	15	4	13	6.5
LSD (0.05)	8	NS	NS	3.6

Table 5. ANOVA table for the factorial analysis between weed control method (mowing, 2,4-D. or Ortho Weed B Gon®), forb planting method (seeding or transplanting), and the interaction effect on grass density, forb density, weed density, and aesthetic value rating (2015 only). Data from the 2 years (2014 and 2015) were analyzed separately.

Effect	**Mean Square**	**F-Value**	***Prob>F***
2014	Grass density		
Weed control method	68.10	2.74	0.11
Planting method	9.39	0.38	0.55
Weed control x planting	56.03	1.13	0.36
	Forb Density		
Weed control method	9.35	2.86	0.14
Planting method	42.01	12.87	<0.01
Weed control x planting	8.76	2.69	0.12
	Weed Density		
Weed control method	84,186.89	1.62	0.25
Planting method	70,437.56	1.35	0.27
Weed control x planting	77,564.39	1.49	0.27
2015	Grass Density		
Weed control method	3.79	0.13	0.88
Planting method	0.01	0.00	0.98
Weed control x planting	5.18	0.18	0.84
	Forb Density		
Weed control method	3.35	0.79	0.48
Planting method	85.50	20.01	<0.01
Weed control x planting	1.13	0.27	0.77
	Weed Density		
Weed control method	5,156.60	1.52	0.27
Planting method	4,933.56	1.45	0.26
Weed control x planting	6,760.18	1.99	0.19
	Aesthetic Rating		
Weed control method	1.06	0.68	0.53
Planting method	22.22	14.36	<0.01
Weed control x planting	2.06	1.33	0.31

Table 6. Density of grasses, forbs, and weeds as influenced by weed control method (mowing, 2,4-D. or Ortho Weed B Gon®) and forb planting method (seeding or transplanting). Interaction between the two variables was insignificant at *P*=0.05 therefore, data were combined across seeding method or weed control method. Aesthetic value was rated only in 2015 using a subjective rating scale of 1 to 10 with 10=best.

Treatment	**Grasses**	**Forbs**	**Weeds**	**Aesthetic Rating**
	------------------ # plants /m2 -------------------------			
2014				
Weed control method				
Mowing	15.4	2.8	42.8	-
2,4-D	15.6	2.2	229.5	-
Ortho Weed B Gon®	21.3	4.6	9.8	-
LSD (0.05)	NS	NS	NS	-
Planting method				
Seeding	18.2	4.7	31.5	-
Transplanting	16.7	1.7	156.6	-
LSD (0.05)	NS	1.9	NS	-
2015				
Weed control method				
Mowing	14.2	3.9	24.6	6.3
2,4-D	13.3	2.6	70.4	5.5
Ortho Weed B Gon®	14.8	2.7	15.8	6.0
LSD (0.05)	NS	NS	NS	NS
Planting method				
Seeding	14.1	5.2	20.4	7.1
Transplanting	14.1	0.9	53.5	4.8
LSD (0.05)	NS	2.2	NS	1.3

Table 7. Percent of total plant stand made up of each of 5 grass component species and 12 forb component species at the end of the study in Oct 2015. Percentage for grasses and forbs were calculated separately. Grass percentages were based on subjective estimates of stands in each plot. Forb percentages were based on actual plant counts within each plot.

Common Name	**Scientific Binomial**	**% of Total Plant Stand**	**Comments**
Grasses			
Idaho fescue	*Festuca idahoensis*	< 1	Moderate emergence, outcompeted.
Indian ricegrass	*Achnatherum hymenoides*	< 1	Poor emergence, moderately competitive..
Big bluegrass	*Poa secunda*	3	Moderate emergence, moderately competitive.
Slender wheatgrass	*Elymus trachycaulus*	96	Excellent emergence, aggressive and dominant.
Tufted hairgrass	*Deschampsia caespitosa*	0	No emergence.
Forbs			
Yarrow	*Achillea millefolium*	31	Good emergence, competitive.
Pacific aster	*Symphyotrichum chilene*	6	Moderate emergence, competitive.
Purple prairie clover	*Dalea purpurea*	0	Poor field emergence. Seedlings and transplants outcompeted.
Western larkspur	*Delphinium x occidentale*	0	No emergence.
James' buckwheat	*Eriogonum jamesii*	0	No field emergence. Transplants outcompeted.
Blanketflower	*Gaillardia aristata*	27	Good emergence, competitive.
Blue flax	*Linum lewisii*	2	Poor emergence. Seedlings and transplants moderately competitive.
Rocky Mtn penstemon	*Penstemon strictus*	0	No emergence.
Firecracker penstemon	*Penstemon eatonii*	0	No field emergence. Transplants outcompeted.
Black-eyed Susan	*Rudbeckia hirta*	9	Moderate emergence, competitive.
Mexican hat	*Ratibida columnifera*	24	Good emergence, competitive.
Munro's globemallow	*Sphaeralcea munroana*	< 1	Poor emergence, moderately competitive.

Figure 1. Site preparation activities on 28 June 2013 prior to seeding grass component species for the meadow establishment study.

Figure 2. Weed-dominated common-practice control (grass and forbs spring planted, non-weeded) plot on 22 August 2013.

Figure 3. Grass seedlings growing with annual weeds in a mowed (bi-weekly, height 6.4 cm (2.5 in)) plot on 22 August 2013, one week prior to planting forbs.

Figure 4. Grass seedlings growing in a 2,4-D treated plot on 22 August 2013, 1 week prior to planting forbs.

Figure 5. Grass seedlings growing in an Ortho Weed B Gon® treated meadow plot on 22 August 2013, 1 week prior to planting forbs.

Figure 6. Grass seedlings growing in a hand-weeded control plot on 2 August 2013, 3 weeks prior to the planting forbs.

Figure 7. Final appearance of a common-practice control plot (spring-seeded, non-weeded) on 18 July 2015. Note the high density of annual weeds (kochia and mustards) and complete lack of meadow components.

Figure 8. Final appearance of a hand-weeded control plot on 18 July 2015. Note the nice mix of grasses and forbs.

Figure 9. Final appearance of a mowed, fall-seeded plot on 18 July 2015. Note the nice mix of grasses and forbs. Compare Figure 10, photo of a mowed, transplanted plot.

Figure 10. Final appearance of a mowed, fall-transplanted plot on 18 July 2015. Note the sparse but robust forbs. Compare Figure 9, photo of a mowed, fall-seeded plot.

Figure 11. Final appearance of 2,4-D treated, fall-seeded plot on 18 July 2015. Note the dominance of the grasses, but acceptable distribution of forbs.

Figure 12. Final appearance of a Ortho Weed B Gon® ® treated, fall-transplanted plot on 18 July 2015. Note the dense stand of grasses and limited number of robust forbs.

Extra color photo. Meadow establishment research plots located on the Aberdeen Research and Extension Center in southeast Idaho. Photo taken 17 October 2013.